



**FACULTY OF ELECTRICAL ENGINEERING
AND INFORMATION SCIENCE**



**INFORMATION TECHNOLOGY AND
ELECTRICAL ENGINEERING -
DEVICES AND SYSTEMS,
MATERIALS AND TECHNOLOGIES
FOR THE FUTURE**

Startseite / Index:

<http://www.db-thueringen.de/servlets/DocumentServlet?id=12391>

Impressum

Herausgeber: Der Rektor der Technischen Universität Ilmenau
Univ.-Prof. Dr. rer. nat. habil. Peter Scharff

Redaktion: Referat Marketing und Studentische
Angelegenheiten
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Redaktionsschluss: 07. Juli 2006

Technische Realisierung (CD-Rom-Ausgabe):
Institut für Medientechnik an der TU Ilmenau
Dipl.-Ing. Christian Weigel
Dipl.-Ing. Marco Albrecht
Dipl.-Ing. Helge Drumm

Technische Realisierung (Online-Ausgabe):
Universitätsbibliothek Ilmenau
[ilmedia](#)
Postfach 10 05 65
98684 Ilmenau

Verlag:  Verlag ISLE, Betriebsstätte des ISLE e.V.
Werner-von-Siemens-Str. 16
98693 Ilmenau

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ISBN (Druckausgabe): 3-938843-15-2
ISBN (CD-Rom-Ausgabe): 3-938843-16-0

Startseite / Index:
<http://www.db-thueringen.de/servlets/DocumentServlet?id=12391>

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Comparison of methods for the dissipation factor measurement

ABSTRACT

Due to the mechanisms of the liberalised electricity market a change of the maintenance strategy from time to condition based can be noticed. This is a reason why different monitoring-, analysis- and diagnostic systems become an essential part in electric power generation, transmission and distribution systems with the aim to increase the reliability of the whole system. This means that the condition of electric power equipment has to be observed. Normally the operator of power networks applies technical diagnostic tools with respect to operational data. With the known condition, optimal maintenance strategies can be applied, required inspections can be planned on a long-term basis and the whole component lifespan can be utilised.

Monitoring and diagnostic systems provide an evaluation of the operational status like insulation integrity and thermal ageing. For example partial discharge and thermal ageing lead to a change of the physical, chemical and electrical properties of different insulation materials which causes a variation of the dielectric parameters, such as the dissipation factor.

Therefore, in the range of electric diagnostics the dissipation factor measurement plays a major role. The classical method to determine the dissipation factor and the $\tan\delta$ tip-up is the Schering Bridge, which is an AC-balanced bridge circuit. Recently electronic bridges were developed at which no balancing of the bridge is necessary. New computer-based measuring systems operate according to the principle of a vectorial impedance measurement in the frequency range by analysing the fundamental current harmonic of the test object and the reference capacitance. A further possibility is to calculate the dissipation factor from the results of a DC-current method by polarisation and depolarisation of the test object. The time based measuring current is transformed to the frequency based description by means of a Fourier analysis.

In this paper the basics of these three measuring methods (Schering Bridge, unbalanced Bridge and PDC Analyzer) were faced with respect to accuracy, sensitivity and applicability. First a theoretical overview of the measurement methods and technologies is given, followed by practical measurements which should demonstrate the performance of each single method and point out the advantages and disadvantages. For a comparison of the different measuring technologies, the measurements have been done on the same samples at the similar ambient conditions.

1. Introduction

Due to the effect of aging mechanism on to the electric insulation system of power equipment the dielectric behaviour is worsening. Ageing mechanism can be caused by electrical, thermal, mechanical, chemical or ambient loads which effects on to the physical properties. Normally a combination of these loads were present simultaneous, this so called multi stress ageing causes a reversible deterioration or a permanent degradation. In the final stage of the ageing the electric insulation system breaks down and the power equipment falls out. For this reason it is very important to have the knowledge about the insulation condition and in the case of worsening to begin with preventive measures. One possibility for condition evaluation is to apply the methodes of dielectric diagnostics and to evaluate the test results. It can be distinguished in time domain and frequency domain methods, where as polarization and depolarization currents (PDC) and the recovery voltage (RVM) operates in time and the dissipation factor and complex capacitance with Schering Bridge operate in frequency domain [1].

2. Methodes to determine the dissipation factor

The dissipation factor $\tan \delta$ and capacitance of an electric insulation system were specific to material and equipment construction. The dissipation factor is a parameter which is a dimension for the quality of the dielectric losses in the insulation system and it gives the relation between the real and reactive components. With the change of the measuring frequency, e.g. decrease to 0.1 Hz, the sensitivity can be rised. Usually it is taken to evaluate the quality or the change of losses in an insulation system, for example low values equal a very good condition. A rise of $\tan \delta$ is a sign for strong worsening of the insulation condition, mostly caused by internal partial discharges. For this reason often a PD measurement is applied to evaluate the results of dissipation factor measurements.

The classical method to measure the dissipation factor $\tan \delta$ and the capacitance is done with the Schering Bridge.

2.1 Schering Bridge

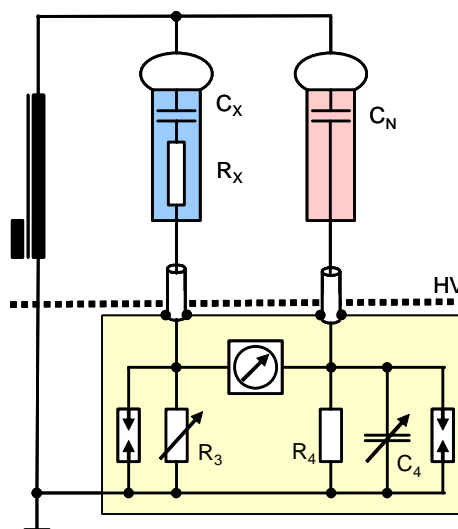


Fig. 1: Capacitance and Dissipation Factor Bridge (Schering Bridge) [2]

The test object and the reference capacitance is set on high voltage, the balancing elements lay on low voltage and with the null indicator the bridge is balanced (Fig. 1).

The balancing condition is fulfilled in the case of same electric potential on both ends of the null indicator respectively no current flow through the null indicator. The accuracy of measurement depends essentially on the sensitivity of the null indicator. The balancing condition can be described with following formular :

$$\begin{aligned} Z_X / Z_3 &= Z_N / Z_4 \\ \tan \delta &= \omega C_X R_X = \omega C_4 R_4 \end{aligned}$$

The result of the measurement is influenced by some parameters, which can be listed as follows:

- Stray capacitance between earth and measuring object as well as earth and standard capacitor (assembling condition, type of fitting). The stray capacitances present the most important source of troubles at the Schering Bridge, for this reason doubled shielded measuring cables were used.
- Surface currents (condition of surface) and leakage currents: to prevent these problems guard rings were applied if possible.
- Environmental conditions: The dissipation factor is dependant from temperature and the moisture content of the test object and the humidity of air. It is almost a linear connection and with a correction factor the measuring result can be rectified.

The dissipation factor is a quantity of material properties, which is essentially dependant of polarization behaviour respectively polarization losses as well as conductivity properties. For high voltage insulation systems a quantity of about 10^{-3} (1‰) and lower describes a good dissipation factor however it is strongly dependant on which materials were used. For example synthetic resin shows a lower $\tan \delta$ as asphalt or shellac insulation systems for generators.

2.2 Vectorial Impedance Measurement in Frequency Domain

The measuring principle is illustrated in Fig. 2a. The currents of the standard capacitor and the test objects were measured and the phase shifting is compared. The currents were measured related to the amplitude and phase, amplified and converted from an analog into an digital signal. With optical wave guides a potential free connection to the computer controlled measuring software enables a automatically evaluation (Fig. 2b). A balancing process as at the Schring Bridge is not necessary any more. The phase shifting of the basic frequency (50 Hz) of both measuring signals is calculated by applying a DFT (Discrete Fourier Transformation).

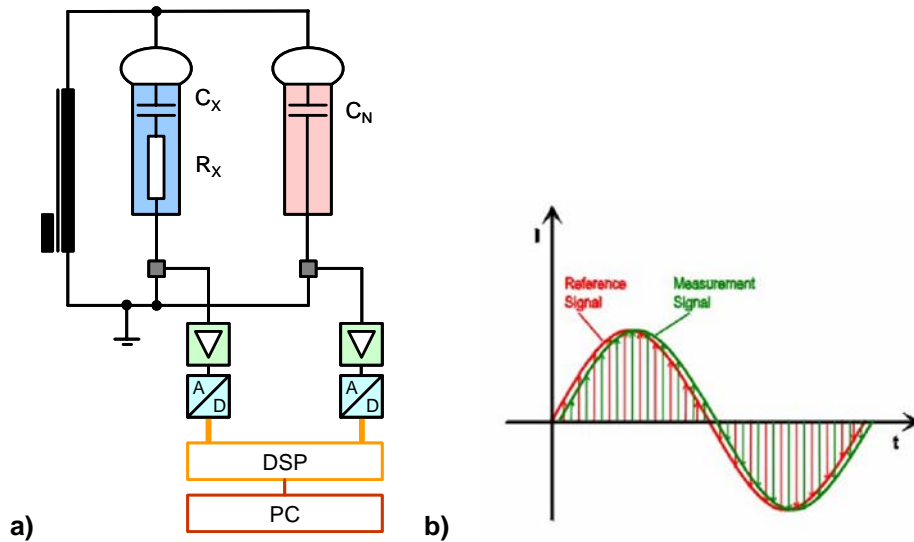


Fig. 2: Schematic Principle of Current Phase Measuring [3]

2.3 Polarizations-/ Depolarization Current Measurement

The dielectric response of an electrical insulation system is measured in time domain at the PDC method. The polarization and depolarization currents in dependence of time were recorded and evaluated as shown in Fig. 3a. The dielectric response function can be described as a linear function in a double log scale, a first mathematical formulation was done by Curie and von Schweidler. The time domain response function is converted to the frequency domain description applying a Discrete Fourier Transformation (DFT):

$$f(t) = \frac{-i_d(t)}{C_0 \cdot U_0} \quad \longrightarrow \quad f(\omega) = \int f(t) \cdot e^{-j\omega t} dt$$

The advantage is that the frequency domain is a complex description of the response function where the parameters conductivity, permittivity and polarization can be described according to the formula:

$$\tan \delta = \tan \delta_L + \tan \delta_{POL} = \frac{\kappa + \omega \epsilon_0 \epsilon_r''}{\omega \epsilon_0 \epsilon_r'}$$

$$\epsilon_r^* = \epsilon_r' - j \epsilon_r''$$

with: κ ... conductivity, $\tan \delta$... dissipation factor, ϵ_r^* ... complex permittivity

The dissipation factor can be expressed according to above formulars where the conductivity and the real part of the complex permittivity show a very low dependence to frequency. The imaginary part has a stronger dependence to frequency caused by different polarization mechanism in the insulating medium. The $\tan \delta$ can be calculated from the real and imaginary capacitance and the conductivity.

The PDC Analyzer was developed to determine the dielectric response behaviour of an electric power equipment. The measurement of the capacitance and dissipation factor was not of main interest. C and $\tan \delta$ were calculated from the measured parameters (Current in dependance of time). The PDC Analyzer is often used to determine the content of water in an insulating medium as paper-oil systems (Transformers or cables).

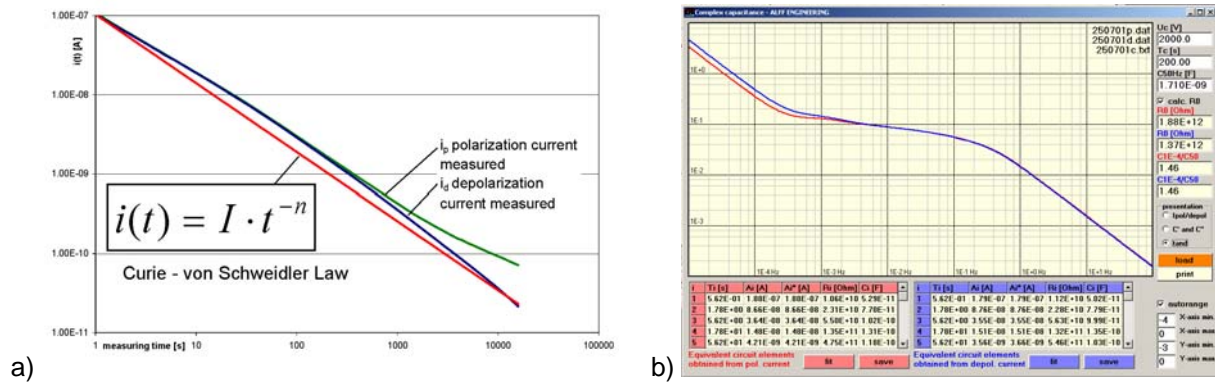


Fig. 3: a) Polarization and Depolarization Currents and b) $\tan \delta$ in frequency domain

3. Test Objects and Test Program

For the comparison of above mentioned measurement methods different types of high voltage equipment was taken to determine the dissipation factor in dependance of the voltage level. Beside different generator bars also some medium voltage cables were tested. The generator bars were of resin rich technology and the insulation medium of the cables XLPE as well as from paper oil type with cable joints and terminations. The test objects were aged naturally in a grid of an utility over some years and set out of operation in a servicable condition. The generator bar models had some artificial imperfections which could be eliminated with a field grading cone.

| No. | Test Object | Technology | # |
|-----|---------------------|---------------------------------|---|
| 1 | Generator Bar | Resin Rich | 1 |
| 2 | Generator Bar | Resin Rich | 2 |
| 3 | Generator Bar | Resin Rich | 3 |
| 4 | Generator Bar Model | without artificial imperfection | 1 |
| 5 | Generator Bar Model | with artificial imperfection | 2 |
| 6 | MV Cable | XLPE-Paper Oil | 1 |
| 7 | MV Cable | XLPE-Paper Oil | 2 |
| 8 | MV Cable | XLPE-Paper Oil | 3 |
| 9 | MV Cable | XLPE-Paper Oil | 4 |

Table 1: Test Objects

The following test program was carried out:

- At first the service aged generator bars were tested with all three systems.
- The generator bar models were tested with and without imperfections.
- The cables wer compared with the Schering Bridge and the results of the PDC Analyzer.

In another test series the results of the dissipation factor measurements were verified with a partial discharge measurement. The PD level was determined in dependance of the applied test voltage. Earlier investigations showed a good correspondance between the rise of dissipation factor and PD inception voltage [4].

4. Test Results

Within the 9 test objects several measurements were done. Due to the extensive test results some examples of measuring analysis should be given. In the first diagram (Fig. 4) one test result of the service aged generator bar models is illustrated. The capacitance and dissipation factor in dependance of the test voltages shows a very good accordance between the electronic bridge and the Schering bridge. The calculated capacitance at 50 Hz from PDC Analyzer differs 4...5% to the measured capacitances. The result of the calculated dissipation factor differs in a greater range (two powers).

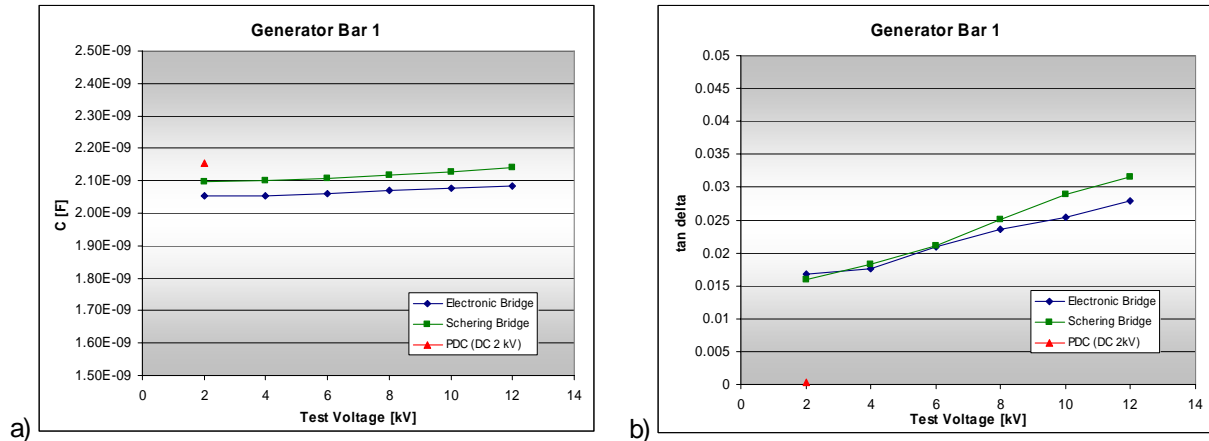


Fig. 4: Test results of a) capacitance and b) $\tan \delta$ measurement generator bars

In Fig. 5 the test results of the generator bar models with imperfections were illustrated. The capacitance values of all test systems were in a maximum deviation of 5%. The dissipation factor of the measured values show a greater deviation at lower test voltages, at the rated voltage a better accordance can be observed.

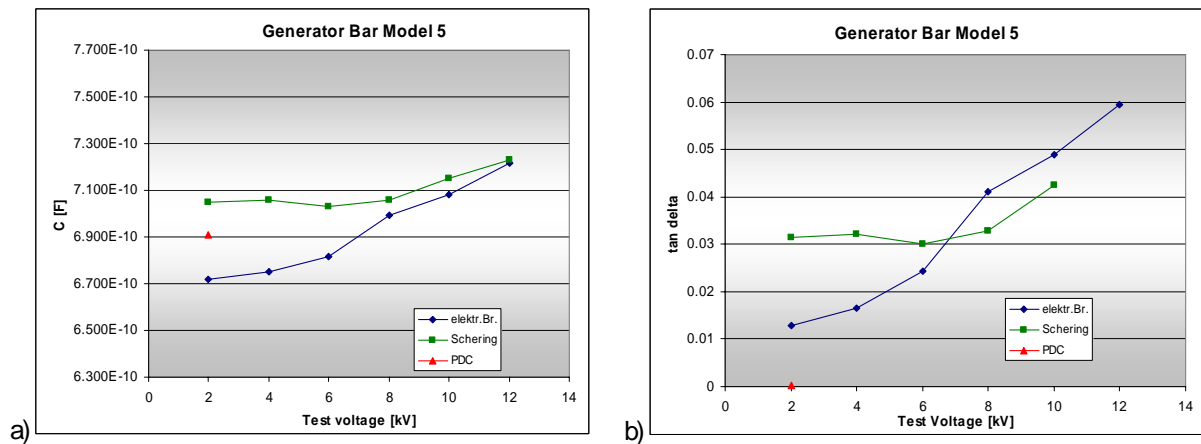


Fig. 5: Test results of a) capacitance and b) $\tan \delta$ measurement generator bar models with artificial imperfections

To verify the correspondance between the measured dissipation factor and the partial discharge behaviour of the generator bars the following diagram was drawn. The measuring results of the electronic Bridge and the results of PD measurement from ICM system were illustrated in Fig. 6. The tendency of the rising dissipation factor, which can be interpreted as higher ohmic losses in the dielectric, represents that higher PDs (PD level in pC and greater nuzmber of discharges) at greater test voltages appear. Starting at 4 kV the $\tan \delta$ is increasing respectively the inception of PDs can also be observed.

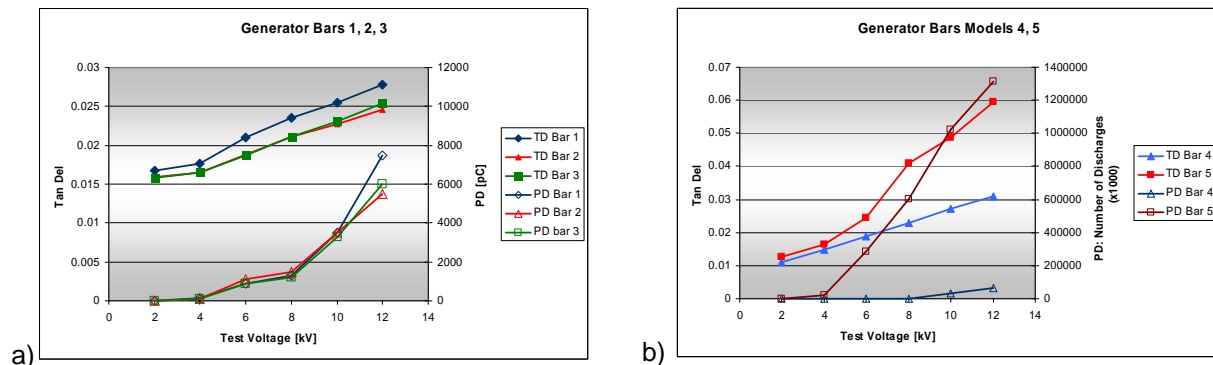


Fig. 6: a) Correspondance of dissipation factor and partial discharge (max. level) at generator bars and b) correspondance of dissipation factor and partial discharge (number of discharges) at generator bar models

The same measurements were also done at the medium voltage cables with terminations and joints. Due to the fact that the cables have a very low PD level (<3 pC at 12 kV) the characteristic behaviour between PD and dissipation factor could not be observed. For this reason the preparation of these results was not further completed.

5. Summary

The results of the capacitance measurements shows that there is a good correspondance between the Schering and the Electronic Bridge. The calculated capacitance values from the PDC Analyzer also shows an acceptable correspondance with a deviation smaller than 5%. It has to be taken into account that the value from PDC Analyzer results from DC measurements and it is a calculated value for 50 Hz, a trending at different test voltages is not possible.

The results from dissipation factor measurements demonstrates also a very good correlation of both measuring systems. The calculated $\tan \delta$ from PDC Analyzer compared to Electronic and Schering Bridge showed a great deviation.

As resume of the investigations it can be pointed out that the electronic and the Schering bridge were almost equal. Modern Schering Bridges are equipped with an automatic bridge balancing unit and an interface for saving the measuring dates directly in a computer file. The C and $\tan \delta$ can be recorded in dependance of the measuring value and with shunts the measuring range can be extended. Mostly a compress-gas capacitor is used as reference unit.

The advantage of the PDC Analyzer is that there is no high voltage AC supply needed. The PDC method was not developed for determining the capacitance or dissipation factor, the most important use of the measuring results can be found in diagnostics of power equipment (e.g. transformer diagnostic).

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